

Explaining a sharp transition from sedgeland to alpine vegetation on Mount Sprent, southwest Tasmania

Kirkpatrick, J.B., Nunez, M., Bridle, K. & Chladil, M.A.

Department of Geography and Environmental Studies, University of Tasmania, Box 252C, GPO, Hobart, Tasmania, Australia 7001; Tel. + 61 02 202 463; Fax + 61 02 202 989; E-mail j.kirkpatrick@geog.utas.edu.au

Abstract. Regular altitudinal sampling of the vascular plant species composition of treeless vegetation on Mount Sprent, Tasmania revealed gradual change between 510 and 820 m, and between 930 and 1050 m, but steep change between 830 and 920 m. The zone of sharp change was the boundary between lowland sedgeland dominated by *Gymnoschoenus sphaerocephalus* and alpine vegetation. Edaphic and topographic conditions varied relatively little along the transect. Two years of temperature and precipitation data were obtained from sites on either side of the boundary, a site near the summit and a site near the lower limit of the sedgeland. These data indicate that the phytosociological zone of change is coincident with a sharp change in mean temperature conditions between the two central sites. Variation in precipitation appears largely unrelated to phytosociological conditions at this scale. This climatic break appears to be consistent in its characteristics with a frequent subsidence inversion layer, and could explain the similar sharp boundaries found elsewhere on Tasmanian mountains. The phenomenon may be widespread in maritime mountains.

Keywords: Boundary; *Gymnoschoenus sphaerocephalus*; Inversion.

Nomenclature: Buchanan (1995).

Introduction

Kirkpatrick & Brown (1987) documented the existence of a sharp phytosociological boundary between sedgeland and alpine vegetation on four mountains of south-west Tasmania. They suggested two alternative hypotheses that might explain how discontinuity in phytosociological space could occur in treeless vegetation within apparently continuous environmental space. One hypothesis followed Ogden & Powell (1979) and Noble (1981) in suggesting an extinction of middle slope species during the climatic and sea level fluctuations of the Quaternary. The alternative, and more easily testable, hypothesis was that climatic conditions did not vary continuously with altitude, but, rather, changed sharply at the location of the boundary.

The objectives of the present study were to determine the nature of vegetation change with altitude on Mount Sprent, and to determine whether phytosociological variation corresponded with variation in climatic conditions. If sharp change was found and it was consistent with climatic variation, the historical biogeographical hypothesis would become unnecessary.

Study area

Mt. Sprent (42°46'S, 146°06'E) is closely similar in all respects including location to the mountains studied by Kirkpatrick & Brown (1987). However, unlike these mountains, Mount Sprent is accessible by foot in less than a day, being the only mountain of its type not well secluded in wilderness. The mountain is formed in weakly metamorphosed Precambrian conglomerates, and has been worked by glacial, periglacial and fluvial erosional processes. Its northern face, although steep, is not cliffed. This face of the mountain is almost entirely treeless, although forest and scrub occur in some valleys below 900 m. The soils under most of the sedgeland and alpine vegetation that constitute the treeless vegetation are highly acid, shallow, muck peats which sit on either bed rock or a shallow gravel or sand horizon. Shrub growth ring and *Banksia* node counts suggest that the last fire that burned on the mountain was probably in 1950, with no variation in fire age within the treeless vegetation (J. Marsden-Smedley pers. comm.).

Methods

Quadrats of 5 m × 5 m were placed along a transect on the northern slopes of the mountain from 510 m above sea level to the summit (1050 m). Quadrats were located every 10 m in altitude, using a frequently recalibrated altimeter. All quadrats were placed on moderate slopes.

The outline cover of each vascular plant species within each quadrat was estimated using the following

scale: 1 = < 1 %; 2 = 1 - 5 %; 3 = 5 - 25 %; 4 = 25 - 50 %, 5 = 50 - 75 %; 6 = 75 - 100%. Aspect and slope were determined using a compass and clinometer. Mean peat depth for each quadrat was determined from five probes of a metal rod. One measurement was taken in the middle of the quadrats, with the other four being mid-distant between the centre and the corners.

The phytosociological data were classified using the polythetic divisive programme TWINSpan (Hill 1979). The species order produced by TWINSpan was adjusted by eye in producing a table of species distribution by altitude. The phytosociological data were also ordinated using global non-metric multidimensional scaling with the default options in DECODA (Minchin 1990). These were: 10 starting configurations; 1-4 axes; rescaling in half-change units; maximum iteration = 100; stopping rule for stress reduction ratio = 0.999; stress stopping value = 0.01; Czekanowski (Bray-Curtis) coefficient. Running means ($n = 5$) for a one axis ordination score were calculated and graphed against altitude. The Kruskal-Wallis k -sample test, a non-parametric alternative to one way analysis of variance (Anon. 1989), was used to determine the significance of the differentiation of altitude, rock cover, aspect, slope and organic soil depth between the groups.

Four meteorological stations were established on the northern face of Mount Sprent. The lowest altitude station was on a knoll at 509 m near the lower altitudinal limit of sedgeland. A second station was placed at 850 m near the upper limit of the sedgeland between a small knoll and the steep upper slopes of the mountain. The third station, at 930 m, was situated on the raised margin of a small plateau above the sedgeland/alpine vegetation boundary. The fourth station was situated close to the summit (1059 m).

Each station was equipped to measure rainfall (mm), relative humidity (% at standard screen height of 1.6 m), air temperature ($^{\circ}\text{C}$, at standard screen height of 1.6 m) and soil temperature ($^{\circ}\text{C}$, at 0.5 cm below the soil surface). Rainfall was measured from 207 mm diameter

large capacity rain gauges at approximately monthly intervals. Relative humidity and air temperature were measured continuously with Campbell Scientific Instrument (CSI® CR201 Humidity/Temperature Probes (accuracy $\pm 3\%$ and $\pm 0.5^{\circ}\text{C}$)), while soil temperature was measured with CSI CR101 Thermistor Probes (accuracy $\pm 0.5^{\circ}\text{C}$). Hourly averages for all instruments as well as daily maxima and minima were recorded.

In general the instruments performed to specification although the performance of the CR201 RH probes deteriorated at uneven rates. A secondary lightning strike on the low altitude station caused a loss of data. Other data were lost due to the recorders malfunctioning at low ($< 0^{\circ}\text{C}$) temperatures. Occasionally rain froze in the gauges. Therefore, salt was used as an antifreeze during winter months.

Daily minimum and maximum air and soil temperature, and relative humidity, data were extracted for all days on which the relevant instruments at all four stations were operational. Data for the individual meteorological variables were expressed as environmental lapse rates, both in toto and by season, and the significance of the differences in the lapse rates between adjacent stations was determined using two-tailed Student's t -tests. In all statistical tests $P < 0.05$ was taken to be significant.

Results

The vegetation

The TWINSpan groups formed a strong altitudinal sequence. The indicator species on the first division was the dominant of the sedgeland, *Gymnoschoenus sphaerocephalus*. This group divided into a small higher altitude sedgeland characterized by *Monotoca submutica*, *Blandfordia punicea* and *Epacris serpyllifolia* (group 3) and a lower altitude sedgeland best characterized by *Boronia citriodora* and *Baeckea leptocaulis*. This latter group

Table 1. Median environmental values and results of the Kruskal-Wallis k -sample test (adjusted for ties) for the TWINSpan groups. H = the H statistic.

Variable	1	2	Group 3	4	5	H	P
Altitude (m)	575	725	845	915	1000	45.8	0.000
Soil depth (cm)	38	29	30	26	21	16.2	0.003
Aspect*	3.0	3.0	3.0	2.5	2.0	12.2	0.017
Rock cover (%)	0.0	0.0	3.5	0.0	0.0	7.9	0.094
Slope ($^{\circ}$)	19	15	19	19	17	3.3	0.504

*1 = nw; 2 = w and n; 3 = sw and ne; 4 = s and e; 5 = se.

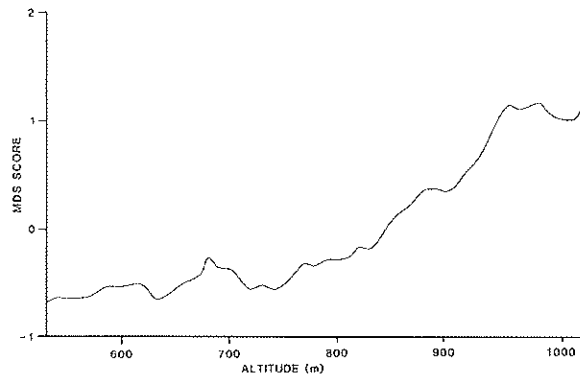


Fig. 1. The relationship between altitude and non-metric dimensional scaling (MDS) score for a one dimensional solution. Running means for five adjacent ordination score values are shown.

also split altitudinally with one group, characterized by *Gleichenia dicarpa*, *Calorophus elongatus*, *Restio complanatus* and *Banksia marginata* (group 1), being found on the lower slopes of the mountain and another, characterized by *Stylidium graminifolium*, *Dracophyllum milliganii* and *Monotoca submutica* (group 2), being found on the middle slopes. The alpine group in the initial division was broken into low alpine vegetation, characterized by *Melaleuca squamea* (group 4), and high alpine vegetation, characterized by *Diplaspis cordifolia* (group 5).

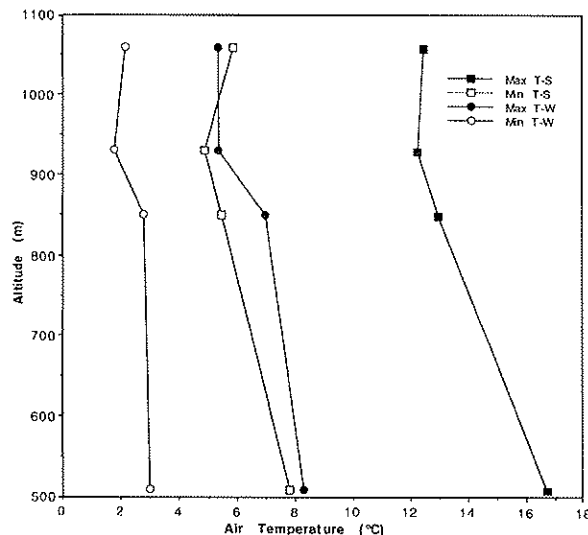


Fig. 2. Mean daily maximum (Max) and minimum (Min) temperature profiles for Mount Sprent in summer (T-S) and winter (T-W).

The groups were strongly differentiated on altitude and less strongly differentiated on soil depth and aspect (Table 1). There was no significant differentiation in either rock cover or slope (Table 1). The groups formed a strong altitudinal sequence with little overlap in ranges (Tables 1 and 2). There is a strong break in species composition between 820 and 930 m, with relative uniformity above and below (Table 2). This break is also apparent in the results of the ordination analysis (Fig. 1). Stress values indicated only one major axis of phytosociological variation. The ordination scores for this axis show a sinusoidal curve for the running means in relation to altitude (Fig. 1).

The climate

Minimum daily air and soil temperatures for the total data set decreased most steeply between 850 and 930 m (Tables 3 and 4, Fig. 2). Above 930 m they increased with altitude. Maximum daily air and soil temperatures declined with altitude, with the steepest decline being between 850 and 930 m and the gentlest being between 930 and 1059 m (Tables 3 and 4, Fig. 2). However, there were no significant differences between the lapse rates for maximum temperatures on the lower slope and those at the transition (Table 4).

Both maximum and minimum daily humidity peaked at 930 m, with a decline both down and up the mountain (Tables 3 and 4), on both humidity variables. The lapse rate between 930 and 1059 m was significantly greater than the other interstation lapse rates (Table 4). Precipitation was markedly least at the summit and varied relatively little below (Table 3).

Discussion

The phytosociological break in treeless vegetation documented by Kirkpatrick & Brown (1987) on other quartzite mountains in the south-west of Tasmania is also present on Mount Sprent. It occurs between 820 and 930 m. Out of the 55 most abundant vascular plants 17 have their upper altitudinal limit in this range and 17 have their lower altitudinal limit in this range (Table 2), which also constitutes the steep part of the sinusoidal curve of ordination values (Fig. 1).

Our data show that the sites occupied by our alpine phytosociological groups are significantly more northerly in aspect and have significantly shallower soils than the sites occupied by our sedgeland phytosociological groups. However, there is as much change in these environmental characteristics within the alpine zone as between the sedgeland and alpine vegetation, making it unlikely that these changes are causal. The peat depth

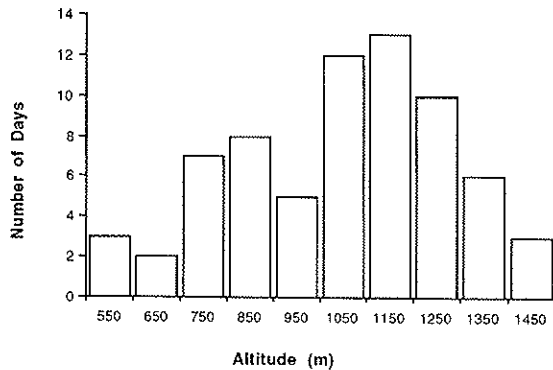


Fig. 3. The frequency distribution of the inversion layer at Hobart Airport, June and July 1994.

changes are more likely to be a consequence of the impact of the climate on vegetation productivity than a cause of the vegetation change. Our climatic data provide evidence for a more convincing explanation of the sharp break. In particular, temperature declines faster with altitude between the two middle stations. Mean summer temperatures are an important indicator of growth potential in superhumid Tasmania and have been shown to be critical in establishing the upper or lower altitudinal limits of species (Pyrke & Kirkpatrick 1994) and vegetation types (Kirkpatrick 1982).

The climatic data are consistent with the presence of a frequent atmospheric inversion between 850 and 930 m (Fig. 2). These regional-scale inversions are related to the atmospheric subsidence which accompanies the passage of a high pressure system over Tasmania. It is possible to observe the height of the inversion base in the free air by examining daily radiosonde soundings at Hobart Airport. These are available daily at 9.00 and 23.00 Eastern Standard Time. There is a wide range of values, with the median being at 1138 m (Fig. 3), indicating that average inversion heights for the free air are slightly higher than those measured at Mount Spret.

Table 3. Means of daily means for the temperature and humidity variables for the four stations and mean annual rainfall over the first two years of recording.

Variable	Station			
	509 m	850 m	930 m	1060 m
Min. air temperature (°C)	5.5	4.1	3.4	4.1
Min. soil temperature (°C)	5.6	5.0	3.5	3.5
Max. air temperature (°C)	14.2	11.2	10.3	10.0
Max. soil temperature (°C)	14.4	10.4	9.0	7.3
Max. relative humidity (%)	94.3	96.0	96.7	94.4
Min. relative humidity (%)	66.4	74.2	75.4	72.1
Mean annual rainfall (mm)	3588	3132	3222	1320

This is not unexpected since radiative cooling at the earth's surface would be expected to bring the height of the inversion slightly downwards (Hobart Airport is near sea level). Also, it is likely that there is a gradual increase in the inversion height as the air flows progressively from west to east over a succession of mountain ranges (Hobart Airport is to the east of Mount Spret).

Subsidence inversions act to trap moisture released by the earth's surface through evaporation. Clouds tend to form at the base of the inversion, where they can gradually thicken into stratocumulus layers, depending on meteorological conditions at the time.

Minimum temperatures, usually occurring at night, would have an average lapse rate of around 0.5 °C/100 m (Nuncz & Colhoun 1986). However, for cloudless conditions the lapse rate would be lower, and for cloudy conditions the lapse rate would be higher (Fig. 4). The lowest temperatures would occur at the cloud top as radiative cooling would be very active at night. The temperature inside the cloud would be one of transition, with the air temperature gradually getting warmer as the bottom of the cloud is reached. Assuming that 'average' conditions represent a mean between these two extremes, the temperature lapse rate would indeed exhibit the strengthening just below the inversion that is indicated in the data from Mount Spret (Fig. 2).

In cloudless conditions the maximum temperature lapse rate is just at or slightly below the superadiabatic lapse rate (1.0 °C/100 m), but it should decrease with cloud cover as surface heating is dampened. The warmest temperatures should occur at or just above the cloud top, due to the high reflection of solar radiation occurring there. Once inside the cloud, there is a rapid decrease in temperature as solar radiation decreases. Vertical temperature profiles taken through stratocumulus layers show that the lowest temperatures occur inside the cloud (Garra 1992). Therefore, average temperatures would also show a strengthening of the lapse rates just below the inversion (Fig. 4), as in the data for Mount Spret (Fig. 2).

Table 4. Means of daily means for environmental lapse rates for daily temperature and humidity variables between adjacent stations. For each variable, statistically identical values ($P > 0.05$) are indicated by identical letters (Students *t*-test).

Variable	Stations		
	509-850m	850-930m	930-1060m
Min. air temperature (°C/100 m)	0.40	0.90	~ 0.55
Min. ground temperature (°C/100 m)	0.18	1.90	~ 0.01
Max. air temperature (°C/100 m)	0.89 a	1.10 a	0.19
Max. ground temperature (°C/100 m)	1.19 a	1.71 a	1.32 a
Max. relative humidity (%/100 m)	~ 0.50 a	~ 0.83 a	1.77
Min. relative humidity (%/100 m)	~ 2.28 a	~ 1.50 a	2.54

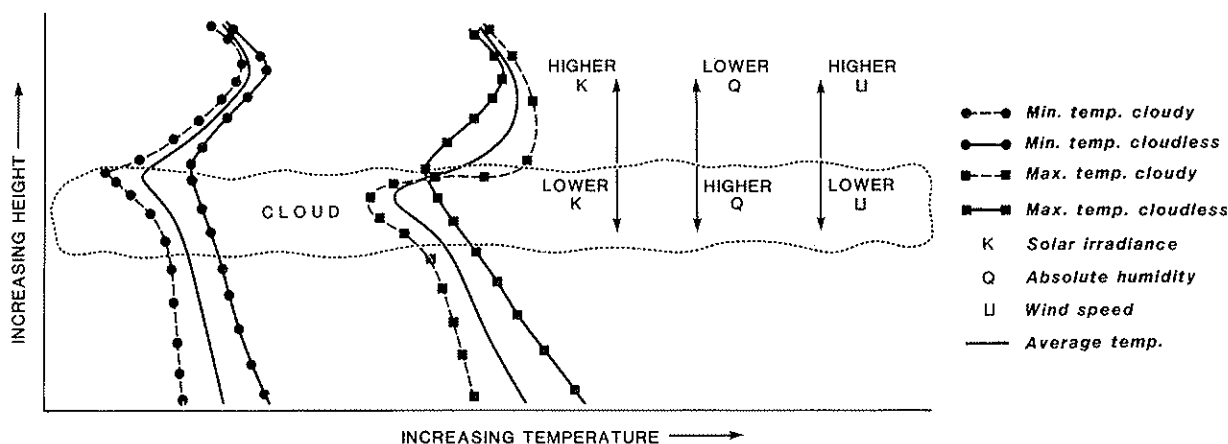


Fig. 4. A schematic diagram of meteorological variation associated with a cloud formed under subsidence inversion conditions. Note that the cloud forms below the inversion.

Other climatic variables would show a marked zonation with elevation in inversion conditions. As mentioned earlier, above the cloud base, solar radiation is intense due to the combined effect of incoming solar radiation and reflected radiation from the cloud top. There is also a sharp gradient in solar radiation just beneath the cloud top, and a sharp transition from mainly direct to diffuse solar radiation. Absolute humidity should also be higher just below the inversion base, in the cloud itself, as is weakly indicated by the Mount Spret data (Table 3). Regional winds above the inversion could be expected to be stronger. Some increase in precipitation would also occur beneath the inversion as a result of drizzle from the cloud itself as well as fog drip. This is again indicated by the Mount Spret data (Table 3).

There is no doubt that the steepening of temperature lapse rates is coincident with the sharp changes in the species composition of the vegetation, and provides a reasonable explanation for its existence. We therefore conclude that our data suggest that the sharp phytosociological break in treeless vegetation on the mountains of south west Tasmania is ultimately caused by a sharp altitudinal break in climatic conditions associated with regional inversions. This type of relationship may prove to be widespread in maritime mountains. There are certainly intimations of the presence of both a sharp phytosociological break and a persistent cloud base on at least one other mountain in Tasmania (Pyrke & Kirkpatrick 1994), in this case, within forest.

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